PERFORMANCE EVALUATION OF GLASS AND BAMBOO FIBRE REINFORCED CONCRETE BY USING TAGUCHI METHOD AND EMPEROR PENGUIN OPTIMIZER

A SYNOPSIS

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1. INTRODUCTION

Concrete is a most widely used construction material today. Concrete is a structural material consisting of a hard, chemically inert particulate substance, known as aggregate (usually sand and gravel), that is bonded together by cement and water. Concrete is the second most used substance in the world after water, and is the most widely used building material. While considering about the mechanical behaviors on concrete, concrete is brittle with high rate of compressive strength. The tensile strength of concrete is comparatively low, which is low as $1/10^{th}$ of the compressive strength of concrete. However, researchers are still analyzing ways to improve the mechanical behaviors of concrete. It is because even though there are advanced materials today, the selection of concrete is the best in terms of economy, durability and load carrying capacity. According to the worldwide usage, it equals twice that of steel, wood, plastics, and aluminum combined.

Reinforced cement concrete (RCC) is one of the ideas researchers use till date to improve concrete properties such as compressive strength, split tensile strength, durability, porosity, flexural strength, water absorption, resistivity etc. RCC is a versatile composite and one of the most widely used materials in modern construction. It is made up of different constituent materials with very different properties that complement each other. Researchers may use different type of reinforcement materials which may vary based on the type of application. RCC is carefully designed and developed since it is a special type of mix designed for a specific application. Even though reinforcement is provided, reinforced concrete may fail, that causes the following secondary effects.

The RCC components may increase the overall weight of the RC structure because of the addition of secondary particles. With respect to the type of particles used,

- RC Structures may take more setting time that may affect the mechanical behavior of the structures such as split tensile strength, flexural strength and porosity.

- Need additional form work and skilled labour. Failing in that, results inimproper reinforcements and even failure of the structures. Improper bonding may arise between the cement, aggregates and the reinforcedparticles.
- High construction costs
- Soil pollution, emissions and related environmental issues etc.

In order to solve such issues a novel RC design is developed and analyzed for mechanical behaviors. In such situation the use of fibres such as bamboo and glass inconcrete is getting researchers attention. Initially asbestos fibres were used as a reinforcing material in fibre reinforced concrete. But, due to its polluting behavior with environment, the asbestos fibres were replaced by other fibre materials like steel, glass and synthetic fibres. Fibre reinforced concrete is mainly used in the places where repair works are required. Fibre reinforced concrete helps to minimize the cavitation and erosion damage. Adding fibres in basic concrete eliminates shrinkage cracking and also prevents water leakage. When fibres are used in bridges it avoids catastrophic failures. Fibre addition also improves flexural strength and can reduce internal forces by reducing the cracks. In high temperature areas generally steel fibres and polypropylene fibres are used to improve the properties of concrete.

The mechanical behavior of any new RC design has to be optimized and validated for economical and mechanical behavior considerations. In such situations statistical methods such as Taguchi, Response Surface Methodology (RSM) are very helpful in designing the experimentations. When it comes to optimization and validation Machine Learning (ML) such as Emperor Penguin Optimizer (EPO) is considered to be the most suitable solution. Because Machine Learning cost less, but outcomes are more accurate. The machine learning algorithms are trained using real time data called Data sets. So, the algorithm starts to learn the problem and the connection between input-output parameters. Finally, the experimental data and the validated data are compared inorder to identify the accuracy and performance of the respective ML model

2. LITERATURE REVIEW

2.1 Concrete

Wangler et al. studied that, after water, concrete is one of the most widely used materials over the world [1]. Concrete has high usability, because of the availability of concrete raw materials, economy and its behaviors such as load carrying capacity,compressive strength and tensile strength. The other benefits are the concrete can be easily formed, maintained and restructured.

2.2 Reinforced concrete

Normal concrete has limitations, especially when it comes to tensile strength, durability, porosity, and resistivity. Normal concrete is not capable of using advanced applications that require special attention. This is especially because of the limited tensile and brittle properties of normal concrete. Normal concrete is low in tensile strength and it is brittle. These limitations of normal concrete will affect the overall load carrying capacity, and there by the durability, porosity and resistivity. In order to overcome these concrete limitations reinforcements have been done. Concrete in combination with reinforcing materials is called Reinforced Concrete (RC). Fiber reinforcements and Steel reinforcements are the most popular reinforcements of concrete. These types of reinforcements may be further classified based on the type of reinforcing material, for example the type of fibre reinforcement [2].

2.3 Fiber reinforced concrete

Afroughsabet et al. studied the causes of crack propagation, elasticity, stress-strain properties, compressive-tensile strength, durability, mechanical and physical properties of concrete due to the fibre reinforcement [3]. Concrete has low tensile strength. It leads to issues like cracks due to drying, shrinkage and plastic properties. These concrete limitations can be controlled by the introduction of fibre reinforcement to concrete. As a result, authors found that the reinforced concrete has

limitations such as workability. The addition of steel fibres reduces the electrical resistivity of concrete to a considerable rate. Naser et al. studied the types of FRP strengthening systems and applications such as flexural, shear, tension, axial and combined loading conditions [4]. Authors had analyzed the performance behaviors of FRP strengthened concrete under elevated temperatures, saline environment, and fluctuating weather conditions such as cycles of freeze and thaw. Finally, authors had concluded that FRP materials have the capability of improving various physical and mechanical properties in concrete structures. However, authors had also mentioned that the performance of FRP reinforced concrete is limited by environmental and loading conditions.

2.4 Bamboo Fiber Reinforcement

Researches show that bamboo is one of the light weight, safest, environment friendly and strongest material as steel fibres. There are many problems going aroundbecause of the concrete wastes. Concrete wastes produce numerous environment hazards. Meanwhile bamboo has many benefits when it is used as a reinforcing material in concrete. Bamboo is less costly when compared to steel or other fibers or materials. Transportation and handling are not hard as steel. It can be easily available.Bamboo is ecofriendly and ecologically degradable. These are the causes that many researchers are looking in to bamboo as a reinforcement material with concrete.

Chin et al. studied that bamboo has excellent mechanical properties, and it is economic and readily available [5]. Structural behavior of bamboo fibre reinforced concrete (BFRC) is investigated. BFRC specimens are made and tested for failure mode, deflection behavior and crack pattern formation under four point bending. Results show that the BFRC reinforcement can have the capacity to divert and mitigate crack formation and propagation. Yao and Li investigated flexural behavior of bamboo fibre reinforced laminates [6]. In order to perform the experimentation bamboo plates of 600 x 50 x 5mm in size were made from fresh bamboos.

Between the reformed bamboo plates and FR mortar sheets a layer of adhesive bonding is given before the specimens are hot pressed. The flexural tests are conducted over the final specimens. Results show that the laminates give flexural strength of over 90 MPa.

2.5 Glass Fiber reinforcement

Glass fibre has the major impact in the concrete and building industry since over 40 years from where the Glass Fibre Reinforced Concrete (GFRC) technique was invented.When compared to ordinary concrete the GFRC has special structure which provides unique mechanical, electro thermal behavior in the building industry. The use of GFRC has wide range of applications and uses including 3D Printing and building complex structures especially when it is used in the thinnest form [7].

Anandaraj et al. tested GFRC under unusual aggressive environments [8]. In order to test concrete behaviors such as compressive strength, flexural strength, split tensile strength, durability and water resistance tests, authors used the special concrete madeof glass fibers, granite, basalt dusts and wastes under varying load conditions and aggressive environmental situations. As a result, authors found that the use of 1% glassfibers with granite and basalt dust particles up to 20% improved GFRC performance to a considerable rate. Authors also noted that when the GF, granite and basalt mix percentage exceeded some percentage, it leads to low reactivity and overlapping particles causing crack formation and propagation in the concrete matrix.

2.6 Bamboo-Glass fibre reinforced concrete (BGFRC)

Bamboo fibre and glass fibre are two different elements. Both have different properties when these materials are individually reinforced at certain percentage with concrete. However, it was expected that the concrete properties are further extended when both of these natural fibres are reinforced together in concrete mix. Of course, optimal percentage of Bamboo-Glass fibre content should be followed in order to achieve optimal

concrete behaviors. Results show that the combined performance of GBF reinforced concrete has outperformed the individual performance of glass fibre reinforced concrete and bamboo fibre reinforced concrete.

2.7 Optimization of fibre reinforced concrete

Yildizel et al. used the combination of Taguchi and extreme vertices optimization methods to improve and optimize the concrete behaviors [9]. During the experimentation authors used silica, metakaolin and glass fibre aggregates in concrete in a “by weight of cement percentage” of 0%, 5%, 10% and 15% in-order to find the relationship between the added ingredients and concrete behaviors such as workability, pre-crack resistance and random distribution. Results show that the proposed optimization method is very effective in solving concrete reinforcement related problems. Calis et al. studied that the reduction of porosity and pore features is a problem in light weight concrete [10]. Authors investigated this issue in light weight concrete by adding ground calcium carbonate (GCC) and glass fibre (GF) in the matrix structure of the concrete. The effects and behaviors such as compressive, flexural strengths and thermal conductivity behaviors are studied by the authors because of the addition of GCC and glass fibre. In-order to bring more accuracy and predictions of the results authors had implemented TAGUCHI optimization in the experimentation. Results show that the use of glass fibers and GCC improved the properties of concrete such as compressive strength, flexural strength and thermal conductivity. The TAGUCHI optimization program is trained with sufficient data and showed that the optimized outcome is closer to the real experimental results.

2.8 Outcome of literature survey

From the literature review, it is found that bamboo is one of the light weights, safest, environment friendly and strongest material as steel fibres. Concrete wastes produce numerous environment hazards. While considering the economical fact, bamboo is cost effective compared to the steel fibres. Transportation and handling of bamboo fibre is not complicated and is easily available. Bamboo is ecofriendly and ecologically degradable and also has excellent mechanical properties. Results revealed BFRC reinforcement can have the capacity to divert and mitigate crack formation and propagation when BFRC is tested against failure mode, deflection behavior and crack pattern formation under four-point bending. The physical and chemical structure of bamboo fibres also affect reinforcement efficiency. Mechanical strength of bamboo fibres got improved when the bamboo fibres are arranged in an order of thin and thickbamboos. Short fibres have more reinforcing efficiency than the longer one. Natural Bamboo fibre shows better performance, when it is short treated with reinforced epoxy-based composites.

From the literature review, it is found that glass fibre has major impact in concrete and building industry. Split tensile and flexural tests shows, the basalt fibre addition has much improvement while glass fibre reinforcement shows no considerable improvement after 0.50% of fibre usage. The use of glass fibers up to 1% with granite and basalt dust particles up to 20% has improved GFRC performance to a considerable rate. GF, granite and basalt mix percentage when exceeded leads low reactivity and overlapping particles causing crack formation and propagation in the concrete matrix.

From the literature review, it is found that, optimal percentage of Bamboo-Glass fibre content should be followed in-order to achieve optimal concrete behaviors. Combined performance of GBF reinforced concrete has outperformed the individual performance of glass fibre reinforced concrete and bamboo fibre reinforced concrete.Tree based ML models performed the best among all other ML models used for comparison in the system. Some

used Response Surface Methodology in order to optimize the fracture behaviors on the steel fibre reinforced concrete (SFRC). Results show that the Response surface methodology prediction provided satisfactory outcome. Taguchi and extreme vertices optimization methods are very effective insolving concrete reinforcement related problems. Reduction of porosity and pore features is a problem in light weight concrete. The addition of GCC and Glass fibre has given possible solution for the reduced porosity issue. Taguchi optimization program is trained with sufficient data and shows that the optimized outcomes are closer to the real experimental results.

3. SCOPE AND OBJECTIVE

In the present world the building construction directly plays a major role in environmental damages and it is our responsibility to find more eco-friendly techniques of construction for infrastructural developments. In order to achieve the eco-friendly construction a new material which is sustainable, economic and naturally available bamboo fibre is mixed with glass fibre in order to enhance more ductility and high tensile strength.

In the present investigation bamboo and glass fibers are used for getting more durable and high strength concrete. Bamboo fiber alone used will be risky in case of earthquake and landslide as these structures have the risk of collapse. In order to overcome this issue an ideal solution for the structure would be adding of glass fibre.

This research work studies to optimize the concrete mix design by using Emperor Penguin Optimization and Taguchi Optimization methods and to validate the bending moment axial force and shear force of the optimized bamboo glass fiber reinforced concrete using ETABS software.

4. EXPERIMENT AND ANALYSIS

4.1 Physical Properties of material

The following materials have been used for the investigation:

1. Ordinary Portland Cement
2. Fine Aggregate
3. Coarse Aggregate
   i)Bamboo splints/sticks
   ii) Bamboo Fibers
4. Glass Fibers
5. Plasticizer
6. Water

Description

Ordinary Portland Cement of 53 grade was used.

Fine Aggregate- Manufacture sand passing through 4.75mm sieve with a fineness modulus of 2.95 and specific gravity 2.58 was used for the entire investigation.

Coarse Aggregate- Crushed Granite angular aggregate of 20mm size with specific gravity 2.61 was used.

Water- Locally available, potable water was used both for mixing and curing of concrete.

Plasticizer

Locally available commercial plasticizer with the trade name 'NANS' was used in this investigation. This is available in granular form in polythene packs containing 100 gms. This has been found to contain sodium salt of Aryl sulphonic acid and sodium alginate mixed with cement and silica.

1% of plasticizer by weight of cement has been used constantly for all ratio of bamboo-glass fibre reinforced concrete.

Bamboo

As per IS code (9096) one-meter length specimens with three and five nodes were cut from bamboo tree of marked brown color which were harvested three years ago. These bamboos were utilized in two different modes in this investigation.

a) Bamboo Splint

b) Bamboo Fibre

Glass Fibre

Alkali resistant glass fibres have been used with a high chemical tolerance and less electrical conductivity. Epoxy coating was given to the glass fibre to prevent the alkali-aggregate reaction. Table 1 represents the physical properties of glass fibre.

Table 1: Properties of Glass Fibre

Properties	**Quantity**
Specific Gravity	2.68
Modulus of Elasticity	72GPa
Tensile Strength	1700MPa
Chemical Resistance	High
Conductivity	Low
Aspect Ratio	857

MIX PROPORTIONS

M30 mix was designed for medium workability by the Indian Standard method givenin handbook on concrete mixes SP-23(S&T). The mix proportion obtained are tabulated below Table 2:

Table 2: Details of Mix Proportion

Materials	**Water**	**Cement**	**Fine Aggregate**	**Coarse Aggregate**
Actual Quantity/m^3	180litres	439 Kg	632.16 Kg	1132.62 Kg
Ratio	0.41	1	1.44	2.58

4.2 Performance Evaluation of Bamboo Stick Reinforced Concrete Beam

In this part of study, the concrete mix was prepared by mixing ordinary Portland cement, fine aggregate, coarse aggregate and water to construct sample concrete beam. The casted beam was reinforced with bamboo sticks which are collected from various waste bamboo culm resources. Due to less intensity caused by high wind flow at the top, the bottom half of bamboo stem (culm) was utilized for making 1m long bamboo sticks which were used as alternate for steel reinforcement in concrete. In depth, the bamboo culms with 3 and 5 nodes were particularly used in this study to avoid longitudinal crack development. The bamboo stick reinforcement was done in two methods such as, single reinforcement and double reinforcement and the results were evaluated with normal concrete beam. In single reinforcement method, one pair of bamboo sticks were reinforced at the bottom portion of the beam, whereas, in double reinforcement method two pairs of bamboo sticks were reinforced at top and bottom portion of the beam. The beams were casted with the help of a mold having inner cavity of 750mm length, 150mm depth and width. After the curing period the flexural strength of

casted beams were analyzed. The ultimate load was increased up to 30kN for double reinforced concrete beam and up to 22.4 kN for single reinforced beam, whereas normal concrete beam had only 12.5 kN ultimate load. Moreover, the maximum deflection was higher for double reinforced followed by single reinforced and non-reinforced beam. Also, the stress strain relationship of 3 and 5 node bamboo sticks were evaluated and an average of 110.66 MPa and 102.54 MPa stress was obtained for 3 node and 5 node bamboo sticks while evaluating 3 random samples. A maximum of 5.5% and 4% of strain was noted while analyzing the stress-strain curves of 3 and 5 node bamboo sticks.

4.3 Performance Study of Bamboo and Glass Fibres Reinforced Concrete

This part of our study comprised of tensile, compressive and flexural strength analysis of glass and bamboo fibre reinforced concrete structure.

4.3.1 Compressive Strength of BGFRC

In order to evaluate the compressive strength, concrete cubes of 15cmx15cmx15cm size were casted for different ratio of fibre content of 1.5%, 2%, 5% and 10% with different hybridization ratio of 25% of glass and 75% of bamboo, 50% of glass and 50% of bamboo and 75% of glass and 25% bamboo were used.

The concrete cubes were tested for 7 days and 28 days after proper curing. From the test results obtained the maximum compressive strength was for 5% fibre content (75%glass fibre and 25% bamboo fibre). The maximum compressive strength was 46.25N/mm^2 and the control specimen has the compressive strength of 38.5N/mm^2. 20.13% increase in strength was achieved with 5% replacement of fibre. The compressive strength was decreased even less than the value of control specimen with replacement of 10% fibre content.

It evidently shows that the workability of concrete was significantly affected due to cluster of fibre and less bonding between the surfaceof fibre and binding material. Fibres randomly oriented in the fibre concrete could result in poor quality of concrete with high porosity.

4.3.2 Split Tensile Strength of BGFRC

In order to evaluate split tensile strength, the concrete cylinders of diameter 150mm and height of 300mm size were used for casting the specimen. The specimen was tested for 7 days and 28 days after proper curing. Specimens were casted for different ratioof fibre content of 1.5%, 2%, 5% and 10% with different hybridization ratio of 25% of glass and 75% of bamboo, 50% of glass fibres and 50% of bamboo fibre and 75% of glass fibre and 25% of bamboo fibre. The concrete cylinders were tested for 7 days and 28 days after proper curing. From the test results obtained, the maximum split tensile strength was 5.52N/mm^2 and that for control specimen the split tensile strength was 4.62N/mm^2. 19.48% increase in strength was achieved with 5% replacement of fibers This split tensile strength has decreased even less than the value of control specimen with the replacement of 10% fibre contents. It evidently shows that the workability of concrete was significantly affected due to the cluster of fiber and less bonding between the surface of a fibres and binding material. Fibers randomly oriented in concrete could result in poor quality of concrete with high porosity.

4.3.3 Flexural Strength of Bamboo Glass Fibre reinforced concrete (BGFRC)

In this investigation, studies involved to evaluate the flexural strength of bamboo glass fibre reinforced concrete. In order to evaluate the flexural strength, three different sizes of beams were casted and their sizes are 1200mm length x 230mm wide x 300mm depth,1200mm length x 230mm wide x 350mm depth and 1200mm length x 230mm wide x 400mm depth. Concrete is mixed with various ratios of fibre (1.5%, 2%, 5% and 10%)with hybridization ratio of 25% glass and 75% of bamboo, 50% glass and 50%

of bamboo and 75% of glass and 25% of bamboo. The specimens were casted and tested for 7 days and 28 days after proper curing. From the test result obtained it was found that, for the 1200mmx230mmx300mm beam, the maximum flexural strength was obtained for 5% fibre content with hybridization ratio of 75% glass fibre and 25% bamboo fibre which is 7.60N/mm^2 after 28days. The control specimen has a flexural strength of 6.12N/mm^2. It was found that, there is an increase of 24.18% in the flexural strength of the fibre reinforced concrete beam as compared to normal concrete beam. From the test result obtained it was found that, for the 1200mmx230mmx350mm beam, the maximum flexural strength was obtained for 5% fibre content with hybridization ration of 75% glass fibre and 25% bamboo fibre which is 8.90 N/mm^2 after 28 days. The control specimen has a flexural strength of 6.55N/mm^2. It was found that, there is an increase of 35.87% in the flexural strength of the fibre reinforced concrete beam as compared to normal concrete beam.

From the test result obtained it was found that, for the 1200mm x230mmx400mm beam, the maximum flexural strength was obtained for 5% fibre content with hybridization ratio of 75% glass fibre and 25% bamboo fibre which is 9.70 N/mm2 after 28 days. The control specimen has a flexural strength of 6.95N/mm2. It was found that, there is an increase of 39.56% in the flexural strength of the fibre reinforced concrete beam as compared to normal concrete beam.

4.4 Optimization of Concrete Mixture and Fibre Proportion

In this part of our study the proposed M30 grade concrete mixture and the ratio of glass and bamboo fibers in concrete reinforcement were optimized with the help of Taguchi and Emperor Penguin Optimizers and the results were analyzed to identify the optimal combination.

4.4.1 Study of Taguchi Optimizer

Taguchi was a statistical method, which optimize the design input parameters to minimize the variation based on orthogonal array proposed by

Dr. Genichi Taguchi. Taguchi model can reduce the variations in output values in the presence of noise. Based on our experimental data, the variation in output parameters (compressive strength of reinforced concrete after 7 and 28 days of curing, split tensile strength of reinforced concrete after 28 days of curing) with respect to input combinations such as, reinforced fibre concentration in concrete, percentage of glass and bamboo fibres, treated and untreated bamboo fibre reinforcement the Taguchi model was trained. The signal to noise (SN) ratio was obtained from designed Taguchi model. The designed model suggested the optimal proportion of glass and 0.25% to obtain maximum compressive strength and 0.75% and 0.25% of glass and bamboo fibre to obtain maximum tensile strength.

4.4.2 Study of Emperor Penguin Optimizer (EPO)

In this phase, the concentration of reinforcement fibers in M30 concrete was optimized with the help of an Emperor Penguin Optimization (EPO) model created in MATLAB platform. Also, the output responses (compressive and tensile strength) with respect to different fibre percentage and variety of glass-bamboo fibre contributions were predicted. The EPO model was trained with experimental data to predict the strength of BGFRC. The EPO algorithm was repeated for 100 iteration to get an optimum result and the factors look stable after 10th iteration. The predicted compressive and tensile strengths were examined with actual results as shown in figure 1 and 2. The obtained results show that the EPO algorithm predicted the optimum tensile and compressive results with an error of 0.11% and0.13%. The predicted optimum combination of glass: bamboo is 0.25:0.75 for compressive and 0.75:0.25 for split tensile strength.

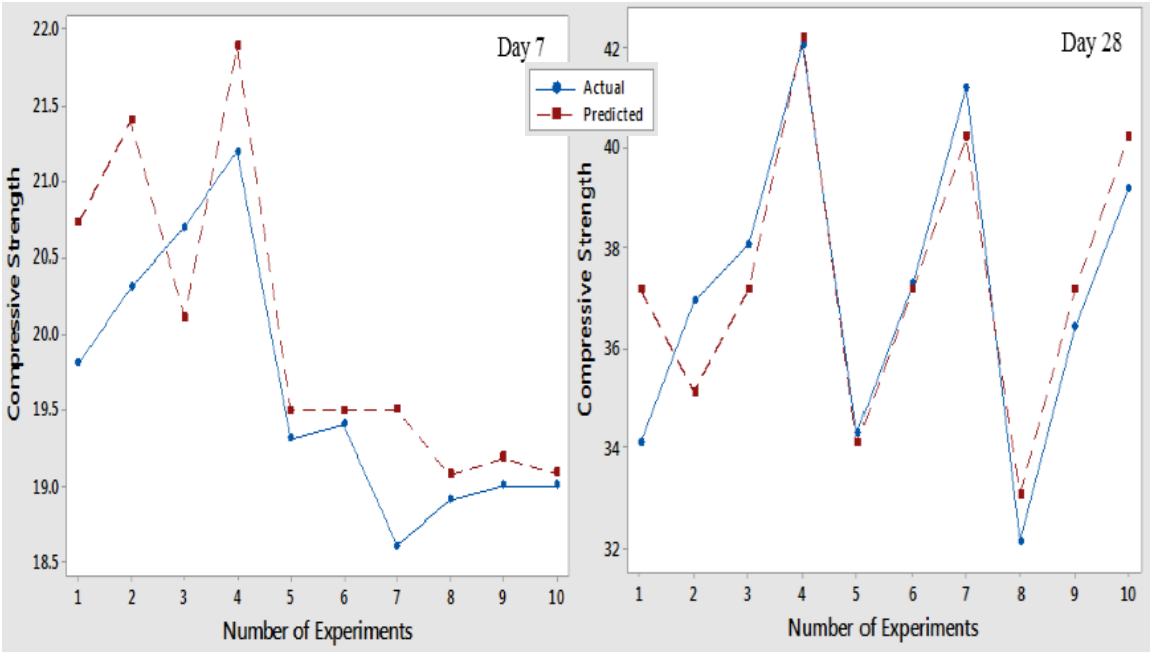

Figure 1: EPO predicted compressive strength vs Actual result

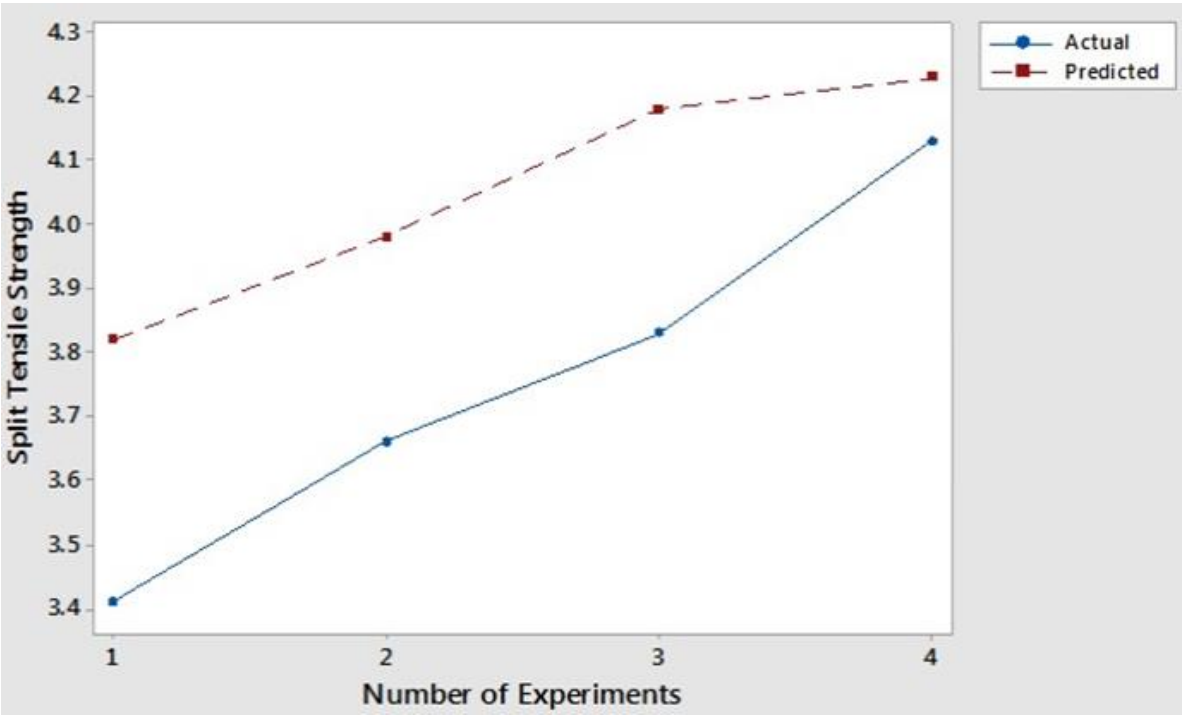

Figure 2: EPO predicted tensile strength vs Actual result

4.5 Validation of Experiment Results

Strength and effects of both reinforced concrete and hybrid fiber reinforced concrete are identified by the comparison study. Comparative study provides the results of both the proposed composition of mixtures with other fibre composition. ETABS software platform is used to carry out the comparative study.Properties like bending moment, shear force, axial force of both the RCC and HFRC are analyzed by using ETABS software platform. ETABS software is clearly recognized as the most reasonable and proficient tool for the static and dynamic examination of the multistoried frame and shear wall structures. This configuration and examination tool speed up information readiness, yield understanding, and execution throughout (Mahmoud et al. 2017). The geometric shape of the model becomes a key issue of the modelling approach. This problem can be solved by analyzing a multi-storied building. ETABS is used to set up the whole model geometrically. It is easier to set up a high-rise building and mesh the whole structure with the pre-processing function of ETABS.

The X and Y axis of reinforced concrete shows large displacement than the hybrid fibre reinforced concrete. Higher displacements are indicated in first storey of the building and are reducing with respect to the increase in storey level. ETABS platform is used to evaluate the reinforced concrete and hybrid fibre reinforced concrete building displacements. The first storey of the building has higher displacement and the displacement reduced in higher storey levels of building. Reinforced concrete building has higher rates of displacement than the hybrid fibre reinforced concrete building in each storey level. The properties like bending moment, shear force and axial force are obtained high in reinforced concrete buildings and optimal in the hybrid reinforced concrete structures. Comparing the results reinforced concrete structure have higher bending moment values than hybrid reinforced concrete structures. The bending moment values

increased with increase in storey level of building. Considering the results, increase in the level of building storey increases the value of shear force. Reinforced concrete shows maximum shear force value of 116.2393 kN and the hybrid fibre reinforced concrete shows maximum value of 98.0225 kN.

Axial force values increased with increase in level of storey. Maximum axial force of RCC is obtained as 475.2463 kN and the maximum axial force value of HFRC is obtained as 416.3457 kN. The proposed bamboo-glass fibre reinforced concrete shows better and optimized results in all cases of testing.

5 CONCLUSION

5.1 Bamboo stick reinforcement

The bamboo stick reinforced concrete structures are not effective in resisting cracking because, the bamboo sticks have weaker elasticity modulus than steel. Besides, the reinforcement of bamboo sticks considerably increases the load- bearing capacity of beams. It was found that, the load-bearing capacity of plain concrete beam increased up to 2.5 and 2 times while reinforcing with double and single layers of bamboo sticks.

On further investigation of 3 and 5 nodded bamboo sticks, the bamboo stick with 3 nodes attained an average of 110.66MPa, stress which is 8.12MPa higher than 5 node bamboo stick. Moreover, maximum of 28.53kN and 29.35kN ultimate load values were achieved for 3 and 5 node samples respectively.

5.2 Bamboo-Glass fibre reinforced concrete (BGRFC)

The following conclusions were obtained from the above experimental investigations:

1. Studies conducted on the mechanical properties of glass and bamboo fibre reinforced concrete reveal that

a) Compressive strength was increased by 20.13% for the 5% addition of fibre content (Hybridization ratio of 75% glass fibre and 25% bamboo fibre

b) An appreciable decrease in the compressive strength was recorded for the addition of 10% fibers. (for all hybridization ratio) irrespective of the period of curing. The observation was due to the fact that at higher fibre content workability is reduced. Further there is a lack of bonding between the fibre and the binding materials, which resulted in decreasing the compressive strength.

2. a) Split Tensile strength was increased by 19.48% with 5% addition of fibres (75% of glass fibre and 25% of bamboo fibre)

b) A significant reduction in split tensile strength was observed, with the addition of 10% fibre content (with all hybridization ratio of glass fibre and bamboo fibre) irrespective of the period of curing. It evidently shows that at higher fibre content, workability was reduced, further lack of bonding between the surface of fibres and surrounding binding materials results in decreasing the split tensile strength.

3.a) i)Flexural strength was increased by 24.18% with 5% addition of fibres (with 75% glass fibre and 25% bamboo fibre) for the beam of the beam of depth 300mm.

ii) Flexural strength was increased by 35.87% with 5% addition of fibres (with 75% glass fibre and 25% bamboo fibre) for the beam of depth 350mm.

iii) Flexural strength was increased by 39.56% with 5% addition of fibres (with 75% glass fibre and 25% bamboo fibre) for the beam of depth 400mm.

b) A reduction in flexural strength was observed for 10% addition of fibres (with all hybridization ratio of bamboo and glass fibre). The results were slightly higher than the values of control specimen and significantly less than the values obtained for 1.5%, 2% and 5% addition of fibres.

5.2 Optimization of BGFRC mixture with EPO and Taguchi

The compressive and tensile strength of BGFRC were optimized by Taguchi and EPO methods. The optimum values of compressive and tensile strength obtained from EPO algorithm is 44.21N/mm2 and 5.32 N/mm2. Where, the optimum composition of glass to bamboo fibre in 5% fibre content is 0.75 and 0.25respectively. whereas, the Taguchi model optimized the effective combinations of 0.25% bamboo and 1.125% glass fibre in 5% fibre reinforcement in M30 concrete for optimum compressive strength. Likewise, the optimum combination of glass and bamboo fibre for tensile strength is 0.75 and 0.25 percentage respectively. Moreover, the optimized fibre combination was further validated by using ETABS software. The results found in favour for proposed 5% BGFRC structure.

6. ORGANIZATION OF THESIS

Chapter 1: A detailed introduction of reinforced and plain concrete along with their advantages and disadvantages were discussed in this chapter. General informations about different types of fibres used in concrete reinforcement and their impact towards the environment, merits and demerits of fibre reinforced polymers are also discussed in this chapter. Moreover, the mechanical characteristics of glass and fibre reinforced concrete, significance of our research,motivation, scope and objectives behind this study was elaborated in this chapter.

Chapter 2: This chapter comprised of brief study of previous researches based on fibre reinforced concrete, bamboo fibres in concrete reinforcement and glass fibres in concrete reinforcement. The detailed study of different optimization and validation methods in fibre

reinforced concrete performance evaluation was also given in this chapter.

Chapter 3: The concrete mixture proportion, selection of coarse and fine aggregate, process involved in bamboo collection, glass and bamboo fibre preparation methods are explained in this chapter. The methodology of mechanical testing, instruments used for measuring compressive, flexural and split tensile strength evaluation process, the methodology of Taguchi and EPO algorithm are discussed. Also, reinforced concrete mix design and steps involved in test sample preparation are narrated in this chapter.

Chapter 4: This chapter deals with the methods and steps involved in performance evaluation of bamboo reinforced concrete beam. The compressive, tensile and flexural strength results are also discussed in this chapter.

Chapter 5: The properties of glass and bamboo fibre reinforced concrete was explained in this chapter. The details in mechanical test and results along with negative impact of bamboo fibre reinforcement and their probable remedies are given in this chapter.

Chapter 6: The optimized results obtained from Taguchi and EPO optimizers were discussed in brief in this chapter. Further, the validation of optimum results was done with the help of ETABS software.

Chapter 7: The overall obtained compressive, tensile, stress-strain and flexural results of bamboo sticks and BGFRC were comparatively analyzed in this chapter to identify the effective reinforcement method for concrete. Also, the prediction performance of EPO algorithm was evaluated with experimental results.

Chapter 8: The final conclusion of our study was discussed in this chapter. Moreover, the scope for future studies based on bamboo and glass fibre reinforcement method in concrete was addressed in this chapter.

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